

## **Improving Anglian Water's emergency response for reservoir safety**

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**SYNOPSIS** The immediate and fast drawdown of a reservoir is often one of the initial steps to be taken in an emergency. This paper covers three main aspects of a project to improve emergency response at five reservoirs: drawdown criteria, optioneering and implementation. There are currently no consistent guidelines or standards as to an acceptable rate of drawdown, although various technical papers have proposed different criteria. In 2005 Anglian Water commissioned consultant Black & Veatch, together with Anglian Water's Reservoir Supervising Engineers, to assess drawdown rates for sixteen reservoirs. Rates proposed were such that it should be possible to reduce the volume of water in the reservoir by:

- 50% in 10 days for impounding reservoirs, assuming zero inflow.
- 50% in 20 days for pumped storage reservoirs and reservoirs that are large compared with their catchment.

It was found that five of the reservoirs did not meet these criteria. The requirement to improve drawdown was subsequently requested by the Inspecting Engineer at four reservoirs and the requirement to improve the rate of drawdown was made a matter of safety under the Reservoirs Act. A further study carried out by the Anglian Water @one Alliance took place to investigate options and costs. The options included:

- Modifying or providing additional scour and draw off facilities
- Using backflow through the inlet pipework
- Installing a penstock or valve through spillweir
- Temporary measures

Options were selected for all five reservoirs and implementation is now complete at two reservoirs and planned at the other three reservoirs.

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### INTRODUCTION

Anglian Water owns 46 large raised reservoirs (storage volume > 25,000m<sup>3</sup>) which are supervised under the requirements of the Reservoir Act 1975, including eight reinforced concrete service reservoirs and eleven waste water facilities/lagoons. They were built between 1863 and 2011.

There are 27 reservoirs impounded by dams, the largest of which is Rutland Water at 124Mm<sup>3</sup>. These raw water storage reservoirs form important storage facilities for water supply purposes and are an important part of Anglian Water's strategic infrastructure. They are of high ecological value sustaining a diversity of wildlife and are also valuable recreational amenities enjoyed by local communities. Some of these reservoirs are close to large conurbations in the region. Anglian Water takes its responsibility for the safety of its reservoirs seriously and has internal quality procedures to ensure compliance with the Act.

These reservoirs are subject to regular surveillance and inspection by operational staff, Supervising Engineers and independent Inspecting Engineers. There is an existing drawdown plan for each of these reservoirs in the event of an emergency.

The rate at which a reservoir may be drawn down is a key part of the safety of a dam and its emergency plan. The immediate and fast drawdown of a reservoir is often one of the initial steps to be taken should a reservoir safety problem arise.

The drawdown rate is not only dependant upon the hydraulic facilities available at each dam through the inlet, outlet and scour pipes but also has to take into consideration the stability of the embankment. Although there are several instances of minor surface failures occurring during rapid drawdown in the United Kingdom, there are no records of major slope failure having occurred. Because drawdown involves lowering the reservoir level and upstream slope failure is only likely to occur after the water level has been lowered significantly, the threat of dam instability leading to catastrophic failure of dam is remote.

There are no consistent guidelines or standards as to what is an acceptable rate of draw down although various technical papers propose rates. Rates quoted are usually in the region of 0.3m to 0.5m per day or as a percentage of the volume in a number of days.

The proposed rates adopted in the Black & Veatch 2005 study are:

- 50% volume reduction in 10 days for impounding reservoirs assuming zero inflow.
- 50% volume reduction in 20 days for non-impounding reservoirs and reservoirs that are large compared with their catchment.

Based on the above criteria, the drawdown rates at Foxcote, Alton, Pitsford, Grafham and Rutland reservoirs, all impounded by earth filled dams, were found to be too low.

For these five reservoirs, a further study took place to look at various options for improving the draw down facilities at each of the reservoirs. The options include:

- Enlarge / improve existing scour facilities
- Use of mobile / permanent pumps
- Provision of siphon
- Backflow through inlet pipework to the reservoir
- Install penstock / valve through spillweir
- Provide a new pipe through the dam or at low point in the rim

The Black & Veatch study provided an opinion on whether the present drawdown rates were satisfactory, but the final decision on that rests with the relevant Inspecting Engineer. The studies undertaken provided the necessary information to the Inspecting Engineers so that they could make an informed decision at the Section 10 inspection on whether to recommend improvements.

Key data for the five reservoirs are shown below:

<b>Reservoir</b>	<b>Dam height (m)</b>	<b>Storage volume (Million m<sup>3</sup>)</b>	<b>Year of construction</b>
Alton	22	9.1	1976
Foxcote	10	0.8	1957
Grafham	26	57.8	1964
Pitsford	22	17.6	1956
Rutland	37	124	1975

The reservoir drawdown facilities at Foxcote and Alton were successfully improved and signed off by the Inspecting Engineer in 2010 and 2011 respectively. Pitsford, Grafham and Rutland are currently under further detailed study/outline design with future construction work planned.

#### FOXCOTE

Foxcote Reservoir is located approximately 2km north of Buckingham. This reservoir is currently not used for supply. The Top Water Level (TWL) is 103.4mAOD and the reservoir has a surface area of 0.204km<sup>2</sup>.

Foxcote Reservoir is an impounding reservoir and has no pumped feed. Water abstraction from Foxcote Reservoir for supply purposes ceased in 1994. Since the reservoir is no longer used, the outlet pipe has been abandoned. The only current draw down facility is the 225mm diameter scour pipe. With flow discharged through the scour pipe, the total time to draw down is about 48 days.

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With the reservoir out of service, there are no implications associated with the works in regard to interruption of supply. The preferred solution for increasing drawdown capacity to 50% volume reduction in 10 days was to modify the outlet pipe by installing a 450mm tee into the existing disused outlet pipework so that releases can be made into the spillway stilling basin (Figure 1). The work was completed in 2010.



Figure 1. A 450mm tee installed at reservoir outlet pipework, Foxcote Reservoir

### ALTON

Alton Reservoir is located about 8.5km south of Ipswich in Suffolk and is a pumped storage reservoir supplied by pumping from the River Gipping. The TWL is 23.77mAOD and the surface area of the reservoir is 0.164km<sup>2</sup>.

Alton Water is a recent, well designed and constructed reservoir, with good instrumentation. The previous emergency drawdown facility at Alton was via use of an existing 300mm scour pipe (Figure 2) in conjunction with the supply pipe washout. The use of the washout from the supply pipe greatly reduces the supply of raw water to the treatment works. Therefore there is reluctance to implement a full emergency drawdown unless the danger was very obvious. Options to increase the drawdown were to:

- increase the size of the scour pipe
- increase the outlet pipework from 700mm to 800mm
- use mobile pumps
- provide a siphon
- backflow through inlet pipework

These were all studied and evaluated, but all apart from increasing the size of the scour pipe were considered to be either not practical or not economical.

The existing scour pipe comprises a submerged 800mm inlet which reduces to a 600mm valve followed by a 25m length of 300mm pipe discharging

into the dry draw off tunnel. It was found that it would be possible to replace the length of 300mm with 600mm pipe. There is insufficient space to enlarge it further to 800mm. Modelling showed that increasing to 600mm would increase the maximum discharge capacity to achieve an outflow of 50% volume reduction in 12 days.

Although the preferred option can only achieve 50% volume reduction in 12 days, the Inspecting Engineer agreed that this could be considered as the preferred option providing other measures, such as an increased surveillance regime, are in place to reduce the risk of an incident. It was also noted that in an extreme event temporary measures such as mobile pumps could also be deployed.



Figure 2. Existing 300mm scour pipe, Alton Water



Figure 3. Enlarged 600mm scour pipe, Alton Water

Downstream of the stilling basin the receiving watercourse passes under a B road and through a disused mill. This area had previously been improved to cope with the previous drawdown rate. It is not anticipated that further improvement will be planned as drawdown would be done initially at a rate that does not cause flooding, increasing the rate only if the situation worsens.

The scour pipe enlargement project was successfully completed (Figure 3), and draw down tested and witnessed by both the Anglian Water Reservoir Supervising Engineer and the Inspecting Engineer, at the end of 2011.

#### PITSFORD

Pitsford Reservoir is located approximately 9km north of Northampton. The TWL is 89.92 mAOD with a surface area of 2.99km<sup>2</sup>. The reservoir is supplied by natural inflow from the direct catchments of the Walgrave, Holcote and Scaldwell Brooks and by pumping from the River Nene.

The primary draw-off facility is via three inlets at different levels discharging into a wet well draw-off tower. A tunnel, which is wet upstream of a plug at about the centre of the dam, passes through the base of

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the embankment and carries the 750mm supply pipe. At the downstream end of the tunnel there is a tee installed and flow can be directed either towards the treatment works or discharged into the tailbay. Upstream of the tee to the treatment works there is a 300mm branch discharging into the tailbay. Presently, the downstream end of the supply pipeline is sealed with a blank flange and the opening in the wall of the large valve chamber to the tailbay is bricked over (Figure 4). In an emergency, this blocked wall would have to be dismantled and the blank flange removed. With flow discharged via the supply pipe, with the blank flange removed and the scour pipe discharging into the tailbay, the time to reduce the storage by 50% is about 26 days. Using the scour pipe alone would take over 6 months to empty the reservoir.

There is also a 300mm drain from the wet section of the tunnel controlled by a valve at the plug (Figure 5). This is a manually operated valve and has not been used for many years because of safety issues arising out of its location at the upstream end of the blind tunnel.

A particular concern at this reservoir is that the capacity of the scour pipe on its own is just sufficient to balance average winter inflow to the reservoir.

The preferred option to increase drawdown capacity requires a combination of two measures: the removal of the blank flange from the end of the supply pipe and extension of this pipe through the end wall of the tunnel, and the installation of a larger scour pipe through the bulkhead between the wet and dry parts of the tunnel. Other options such as the use of mobile pumps, provision of siphon pipework, a penstock through the spillway and a pipeline through the low point in the rim were considered. These options were found to be not practical or not economical and also have operational difficulties. They were therefore discounted.

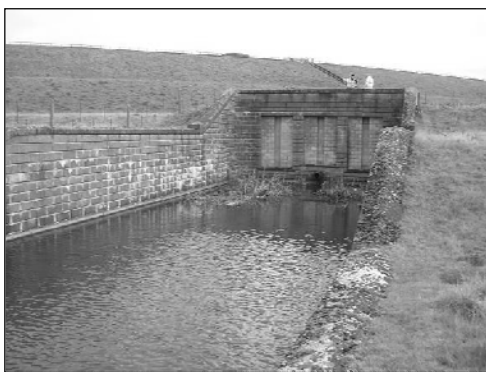


Figure 4. Existing blockwork wall at tailbay, Pitsford Reservoir



Figure 5. 300mm scour valve at concrete bulkhead, Pitsford Reservoir

An option to install a new 750mm pipe through the tunnel plug in place of the existing 300mm pipe has been considered. A 115m long scour pipe would be installed in the dry tunnel and would discharge into the tailbay through the wall at the downstream end of the tunnel. This would involve the draining down of the wet draw-off tower and tunnel and drilling through a 3m thick bulkhead concrete wall using diamond coring.

For the construction phase the installation of the scour pipe through the concrete plug in the tunnel involves isolation and draining down of the wet draw-off tower and tunnel and the provision of over-pumping from the reservoir to the supply pipe to maintain raw water supply for treatment. However, there are a number of risks associated with the works, as below:

- The residual strength left in the concrete bulkhead after core drilling.
- Sealing of the pipework penetration through the concrete bulkhead.
- Keeping the draw-off tower and tunnel dry for the duration of the works and working in confined space.

These will be considered in the final design and construction methodology that is taken forward for approval.

In the 2011 Section 10 report the Inspecting Engineer recommended that the capacity of the scour facilities be increased to 50% reservoir volume reduction within 20 days with inflow equal to average winter flow. The Inspecting Engineer has agreed that the above proposed solution is a practical option and endorsed the selection of it. The works are to be completed before the end of September 2014.

#### GRAFHAM

Grafham Reservoir is located about 9km southwest of Huntingdon in Cambridgeshire. Water is pumped into Grafham from the River Ouse via the diversion tunnel. The TWL is 43.89mAOD and the reservoir has a surface area of 6.3km<sup>2</sup>.

The existing scour pipe is 840mm diameter with a discharge rate of 5.3m<sup>3</sup>/s. Hydraulic analyses indicate that the reservoir could be drawn down from TWL to 24.29mAOD (scour invert level) in 30.5 days. The rate of draw down using only the scour is inadequate. However, removing a section of the inlet delivery pipe or of the outlet supply pipe would considerably reduce the time to reduce the storage to 50%.

There are existing blank flanges installed at the invert of both the supply pipe and inlet pipe, which could discharge into the approach channel underneath (Figure 6). Both inlet and outlet pipe are 1200mm. However, site visits showed that the removal of these blank flanges would be a considerable safety risk. Modelling also showed that this solution does not

achieve the desired drawdown performance, and so this was not considered further.



Figure 6. Blank flange at outlet pipe soffit

Option 1 – Backflow through the inlet pipe to the approach channel. The pumped inlet pipe passes through the draw-off culvert and it would be feasible to install a valved swept tee into the inlet pipe just outside the culvert to drain into the approach channel. This option would not affect water supply for treatment.

Option 2 - Backflow along the inlet pipe back to the River Ouse intake pumping station. The advantage of this option is to avoid any impact on the small Diddington Brook immediately downstream of the approach channel. The reverse flow from the reservoir inlet could be discharged into the balancing pond before the intake pumps. This would then be able to drain into the River Ouse without causing serious flooding.

Both options meet the desirable draw down rate. Option 2 makes best use of existing pipework and would reduce the risk of flooding upstream, whereas Option 1 provides the best draw down rate but would lead to flooding of the small Diddington Brook.

In 2010, invasive shrimp were spotted by anglers at Grafham Reservoir. The shrimp has never been found in the UK before and is native to the steppe region between the Black Sea and the Caspian Sea. It preys on a range of species, particularly native shrimp - and even young fish. This alters the ecology of habitats it invades. All discharges to the watercourse from the reservoir at Grafham are therefore currently prohibited by the Environment Agency until further notice. Anglian Water has installed a protective screen with fine aperture at the discharge channel as a precautionary measure to prevent the potential release of the species to the



downstream environment (Figure 7), as could be the case with either of the above options. The shrimp does not affect potable water quality.



Figure 7. Fine screen at discharge channel to prevent the release of any invasive shrimp

#### RUTLAND

Rutland Water is located approximately 8km east of Oakham in Leicestershire. The reservoir is impounded by an earthfill embankment dam across the valley of the River Gwash. It is a pumped storage reservoir and is very large in comparison with its direct catchment area. The TWL is 83.82mAOD and the reservoir has a surface area of 11.61km<sup>2</sup>.

There are four outlet levels from the reservoir. The bottom outlet is through the tunnel used for river diversion during construction. The upper three outlets are 1200mm pipes laid from forebays into the outlet shaft. The outlet shaft contains twin 1200mm standpipes with isolating valves. This enables water at different levels to be discharged simultaneously to the river and to supply if required due to variations in water quality.

The 1200mm supply pipe runs through the 715m long tunnel. Near the downstream tunnel portal, the supply pipe connects to a tee branching off to the left leaving a continuation of the pipe isolated by a valve with a jet disperser downstream of it for emergency drawdown use. It discharges to a tailbay with flume (Figure 8). The tailbay also accepts flow from the lower half of the tunnel (scour) and overflow from the treatment works pumping station.

The scour pipe of the reservoir is built into the lower half of the concrete plug in the upstream tunnel below the 1200mm low level outlet pipe. The scour pipe has a 1200mm bellmouth intake and tapers down to 750mm. The scour pipe extends for 40m in the lower half of the downstream tunnel and

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then discharges freely into the lower half of the tunnel. Flow is then discharged into the River Gwash via the tailbay.

Emergency drawdown can be achieved by:

- releases from the scour pipe
- releases through the original river regulation pipe
- releases from the 1200mm supply pipe
- releases from the new 800mm supply pipe



Figure 8. Washouts from the two supply pipes, original on the right, new on the left, discharging to the tailbay

Calculations were made in the 2005 study before the new 800mm supply pipe was installed. Two scenarios were considered – one with supply maintained to the treatment works and the other with the supply shut down and scour releases made from the supply main.

The maximum outflow could be achieved with the second scenario. It would take about 75 days to reduce the volume by 50%. Taking account of the mean winter daily inflow, the times are increased by only 1.6%.

The rate of drawdown at Rutland Water is inadequate. However, the low rate of drawdown must be balanced against the modern design of the dam. The risk of rapid failure of the dam is considered to be very low.

In the 2011 study an option has been considered to increase the existing scour pipe size as at the other reservoirs; however access to the submerged part of the scour pipe and risks associated with the higher flow damaging the inside of the draw-off tunnel meant that this option was not practical.

Instead the preferred option was to draw down by reversing flow in the inlet pipes. The feed from the abstraction pumping stations enters the reservoir through jet inlets. The pipe to the inlet structures rises to above the crest

level of the dam and thus simple backflow would not be possible. The inlet aqueduct diameters are up to 1.8m in diameter.

It is proposed that reverse flow would be achieved by:

- Installing new air valves on the inlet siphon over the dam that could be closed to generate reverse siphon flow if the inlet pumps were stopped.
- At Empingham pumping station the aqueduct joins the pumping stations above a shaft. At this point, two 1.8m diameter blank flanges(Figure 9) can be removed from the outlet (now inlet) pipework to allow extension of the reverse flow pipework to take flow from the inlet level down through the floor of the pumping station to join the overflow culverts at the top of the shaft.
- An energy dissipating arrangement would also be needed on the pipework entering the culvert to reduce the head of more than 30m driving the flow and avoid damage to the culvert.
- The overflow culverts discharge to the River Gwash.

This option has the advantage that much of the pipework is already in place minimising cost and disruption. The disadvantage of this option is the potential effect on the River Gwash and infrastructure in its downstream catchment. Therefore a variation on this option has been considered allowing the drawdown flow to fill the shaft and reverse flow down the tunnel to Tinwell intake pump station at the much larger River Welland.



Figure 9. Blank flanges at Empingham pumping station

Of these options, only the reversing flow in the inlet option appears to approach the drawdown requirements. The time to empty the reservoir to 50% of its volume meets the 20 days requirement.

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### IMPLEMENTATION

For the five reservoirs at which the existing drawdown rates are to be improved to meet the desirable requirements, so far Foxcote and Alton have been successfully completed with improved drawdown facilities. Pitsford and Grafham are planned to be included in the current Asset Management Programme (AMP5). Rutland Water, being the largest and most complicated site, will most likely be implemented in AMP6.

The prime driver of these drawdown facilities improvement works are statutory requirements for reservoir safety. Anglian Water's approach is to consider each reservoir improvement works through a detailed risk and value process which includes costs and benefits, whole life cost, health and safety implications, constructability, and sustainability issues including associated environmental impacts and embodied carbon.

Throughout the process key stakeholders including operational colleagues, the Supervising Engineers and Inspecting Engineers are consulted to ensure that the solution meets approval from all parties.

### CONCLUSIONS

It is of paramount importance to establish clear and concise drawdown criteria at the outset for both impounding and non-impounding (pumped storage) reservoirs, in consultation with the Reservoir Supervising Engineer and Inspecting Engineer. In most cases, the preferred methods for improving the existing drawdown facilities involve the enlargement of scour pipes, utilising the washout facilities of the supply pipework or reversing the flow in the pipelines. At some reservoirs, emergency drawdown can affect the supply for treatment. In most cases at Anglian Water reservoirs the use of mobile pumps and installation of siphon are considered uneconomic and impractical because of long mobilisation time.

### REFERENCES

- Black & Veatch (2005). *Reservoir draw down rates study for Anglian Water Services Ltd.*
- @One Alliance (2011). *AMP5 Risk & Value Report on reservoir draw down study for Alton, Pitsford, Grafham & Rutland Reservoir*